Will Climate Change Spark More Wildfire Damage?

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INSURERS ARE ACUTELY AWARE THAT 85 PERCENT OF CATASTROPHE-RELATED PAYOUTS ARE DUE TO NATURAL DISASTERS, with claims averaging about $10 billion per year worldwide over the past decade. For a host of reasons, some better understood than others, these losses are on the rise. A recent study by the Insurance Services Office (ISO), entitled "The Wildland/Urban Fire Hazard," spotlighted one component of this trend. According to ISO, wildfires are a pervasive insurance risk, occurring in every state in 1996 and consuming an average of 5 million acres per year across the United States. Between 1985 and 1994, wildfires destroyed more than 9,000 U.S. homes at an average annual insured cost of about $300 million. For comparison, this was triple the number of homes lost during the three decades before 1985. Some of this increase is attributed to new home developments in high-risk areas.

According to ISO, of the 38 costliest U.S. wildfires between 1825 and 1995, 22 were in California, which ranks No. 1 in terms of economic losses due to wildfire. Insurers feel the effects of wildfire in several ways. Insured property is at risk, and in some cases the costs of fire-fighting or lost timber are underwritten. Wildfire-related injuries or loss of life also exact a cost from insurers. Moreover, in the aftermath of wildfire, secondary events—such as landslides, flooding and water quality impairment—can all impose additional costs. Of course, the insured damages are only a component of the total economic loss and don't reflect the full human hardship wildfires can cause.

The context of wildfire has taken on new dimensions as low-density residential development has expanded rapidly into areas dominated by flammable vegetation, creating a wildland/urban interface. The Oakland/Berkeley Tunnel Fire of 1991 was a poignant example of the enormous damage potential of even a single fire in this interface zone. The third costliest fire in U.S. history, it resulted in $2 billion in insured losses (at 1997 prices), including the destruction of 3,400 buildings and 2,000 cars. Added to this were extensive losses of urban infrastructure, such as phone lines, roads and water systems. The insured losses from this single fire were twice the cumulative amount experienced nationwide during the previous 30 years.

The world's second-largest reinsurance company, Swiss Re, noted that the Oakland/ Berkeley fire may be "a harbinger of a new type of catastrophe that could reoccur on an even larger scale. . . [and] will neither be the only nor the last one of its kind." In its report, "Fire of the Future," Swiss Re underscores that developing homes in wild areas, a pattern that prevailed before the fire, is "a prototype of many suburban areas throughout California and the rest of the U.S." It also points to global climate change as one possible factor influencing the degree of devastation wrought by this and future wildfires.

Improved fire suppression efforts have slashed wildfire damage over the past century. But countervailing forces such as the accumulation of unburned litter and vegetation, increases in human populations and property values at the wildland/urban interface, pressures on fire-fighting budgets and, possibly, global climatic change, could conspire to boost the upward trend in economic losses wildfires cause.

Insurers and climatologists have long known that fire danger is linked to climate, with hot, dry spells creating the highest risk. Concerns over the consequences of global warming were rekindled in 1998 by the impact of El Niño. The powerful impact that climatic anomalies can have on wildfire was demonstrated after droughts linked to El Niño were followed by widespread, devastating fires in Florida, Indonesia and elsewhere. The latest predictions suggest that global warming may also create conditions that intensify wildfire danger by warming and drying out vegetation and by increasing wind speed. Faster fires are much harder to contain, and are thus more likely to expand and cause substantial damage to insured property.

Modeling Wildfire Behavior

We explored how potential global warming might increase wildfire damage in California using a set of state-of-the-art models that simulate fire behavior, fire suppression and climate change. It was designed with protocols to bridge the scales between these different models and to link them to local weather and fire occurrence data. The goal was to produce estimates of climate change impacts on wildfire and the effectiveness of the wildfire suppression system for specific geographic areas.

Global warming may increase the risk of wildfires by drying out vegetation and stirring the winds that spread fires. Detailed models of all the factors that contribute to wildfires have been designed to help insurers reduce the potential for catastrophic loss.

FIGURE 1. CDF State Responsibility Area (SRA) by broad vegetation class

Map created by Jeremy Fried on October 22, 1998, using Fire Management Analysis Zone boundary and attribute data prepared for use with the California Fire Economics Simulator, version 1, in the early 1990s. The authors gratefully acknowledge the provision of this data by Jim Spero of the California Department of Forestry and Fire Protection's Fire and Resource Planning Unit.

To capture some of the complexity of California's landscape, we investigated three climatically distinct and geographically separated areas of northern California: Santa Clara, near San Francisco Bay; Amador-El Dorado, in the Sierra foothills east of Sacramento; and Humboldt, on the northern coast. (See Fig. 1.) Santa Clara and Amador-El Dorado contain substantial areas of wildland/urban interface, and Amador and El Dorado counties were the fastest growing and sixth fastest growing counties in the state, respectively, between 1970 and 1996.

Most of the vegetation fuel types found in the American West are represented in this analysis, including grass, brush (scrub or chaparral), oak savanna and mixed conifer and redwood forests. Each of the three areas modeled is a "Ranger Unit," an area protected by the California Department of Forestry and Fire Protection (CDF) and consisting of all the private and state-owned land not protected by local fire departments. Historically, they're predominantly rural areas, but most are experiencing significant suburban encroachment.

Climate Change Scenarios

The relative certainty that elevated concentrations of greenhouse gases will lead to climatic changes was underscored by the most recent publication of the Intergovernmental Panel on Climate Change (IPCC). The book's findings, representing the consensus of over 2,500 scientists, concluded that detectable, human-induced global warming may already be taking place. While temperatures are predicted to continue to increase over most of the globe as climate change progresses, future changes in other climate attributes will be more complex: Some areas will become wetter and others drier; some areas will experience more cloud cover and others less. Such variation is evident even within California. To understand the implications for wildfire, it's necessary to employ sophisticated climate and wildfire models that incorporate wind speed and humidity as well as temperature and precipitation.

Climate simulation studies performed by general circulation models (GCMs) provide standard scenarios for climate change impact assessments used by government and university scientists around the world, including those in the IPCC. To facilitate comparisons among such studies, analyses are generally standardized to the warming that corresponds to carbon dioxide (CO_2) levels double those that prevailed in the mid-1900s (double CO_2). Barring large changes in global energy use and forest management, atmospheric CO_2 levels will reach this doubling by the middle of the 21st century.

The analysis presented in this article is based on climate simulations from the Goddard Institute for Space Sciences (GISS) GCM for the present and future (double CO_2) climates. GISS predicts that under climate change, the region containing Santa Clara and Amador-El Dorado ranger units will become warmer, windier and drier, while the region containing Humboldt will become warmer but less windy and more moist. Therefore, the effect of climatic change on wildfire severity can be expected to vary geographically.

Creating climate change scenarios for wildfire is complicated by differences in scale. Fire behavior is affected by daily or even hourly weather conditions, but readily available GCM output yields only a monthly average value for each climate variable (temperature, precipitation, wind speed and humidity). In addition, GCM output represents a comparatively large geographic area in which there is a great deal of local variation in weather and fire danger. To bridge scales, our protocol uses the difference in GCM output for present and future (double CO_2) climates to create scaling factors for each month. These scaling factors are used to adjust historical weather data from local weather stations, thereby generating weather data that reflects the predicted changes in climate while retaining the rich temporal and spatial detail of historical records.

Modeling Approach

The attributes of wildfires that make them hard to contain are the rate at which they spread and their burning intensity (an index linked to fire temperature and flame height). By creating warmer, drier fuel conditions and faster flame-fanning winds, global warming may exacerbate both attributes.

In addition to weather, wildfire behavior depends on site-specific characteristics such as slope and vegetation. Our study simulated approximately 700 actual, historical fires representing a typical fire year in California. Each fire's spread rate and burning intensity were modeled—first using historical weather data for that day, and again using climate change "weather."

TABLE 1. Annual fire outcomes under present and future (double CO_2) climate: Effect of population density. Shown with the analysis zones demonstrating the greatest impact of climate change.

	Number of Escaped Fires			Average Size Contained Fire (acres)		
	Present	Future	% Change	Present	Future	% Change
Santa Clara, Grass						
Low Population	2.6	4.7	80%	12.0	16.0	33%
Moderate Population	1.9	2.2	16%	16.4	24.8	52%
Amador-El Dorado, Chaparral						
Low Population	2.4	8.2	242%	5.9	15.5	161%
High Population	2.6	2.9	11%	1.3	2.1	65%

(The day, time, slope, vegetation, location and number of fires were the same in both simulations. The effect of climatic change on fire starts is not a major consideration because over 90 percent of the wildfires in California are started by people.) In places where lightning starts more fires, this aspect of climate change will need to be incorporated into impact analyses.

Based on six years of historical weather and fire records, we used statistically representative fires as input to the California Fire Economics Simulator. CFES is a deterministic model of initial attack on wildfire used by CDF as a tool to evaluate decisions involving the deployment and positioning of fire-fighting equipment and personnel. CFES simulates fire growth and fire suppression by CDF forces until the fire is brought under control or exceeds fire-size or burn-time limits (300 acres or two hours in grass), in which case it's classified as an "escape."

Here, CFES was put to a different use—evaluating the comparative success of fire-fighting efforts against fires burning under present and future climate scenarios. It predicts either the area each fire would burn if the fire were contained or if the modeled fire escapes containment efforts. Unfortunately, the area burned by escaped wildfires cannot be modeled or accurately predicted because the terrain and burning conditions encountered by fires that exceed the escape size or time limits are so variable. The number of escaped wildfires is a crucial measure of wildfire severity because these fires, having overwhelmed initial fire suppression efforts, are considerably more likely to

FIGURE 2. Change in Percentage Point of Fires by Spread Rate Under Climate Change

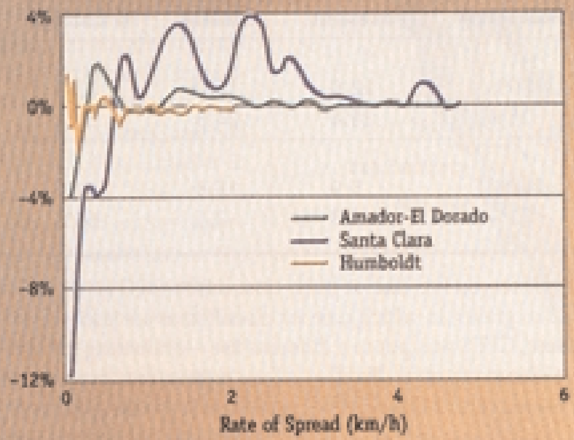


FIGURE 3. Average Number of Fires

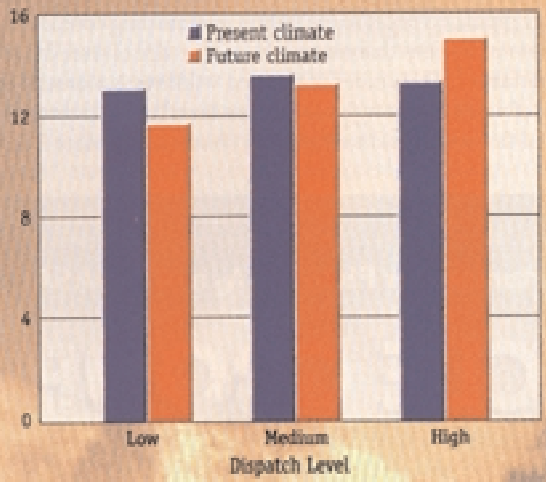
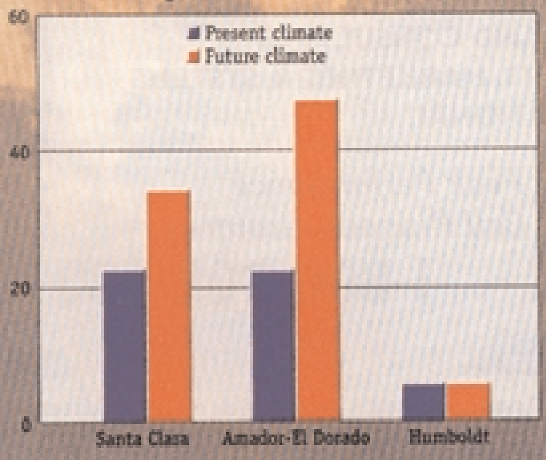


FIGURE 4. Escaped Wildfires per 1000 Fires



become large, damaging fires.

Under current climate conditions, escapes are comparatively rare. Between 1961 and 1997, only 0.03 percent to 0.5 percent of California's wildfires escaped, the range depending on the county. However, likelihood of damage from an escape is large. According to the CDF, one out of every 10 escapes leads to injury or the loss of structures. Moreover, losses generated by some escapes are so large that this category of fire accounted for over half of the fires where structural damage or loss of life occurred, and for well over half of the property value lost to fire in California over the past four decades. While wildfires are less common in forests (compared to brush or grass), those that do occur and escape can be among the most destructive. The increasing density of real estate in forested areas—exemplified by developments in much of the Amador-El Dorado region—represents the potential for enormous wildfire losses.

Results: Fire Behavior

According to this analysis, climatic change will cause fires to spread faster and burn more intensely in most vegetation types (Table 1). The biggest impacts would occur in grassland, where the fastest spread rates already occur. In forests, where fires move much more slowly, impacts would be less severe. Faster fuel types demonstrate a greater response because fire behavior in these fuels is more sensitive to wind speed and the GISS GCM predicts higher wind speeds during peak fire season. The response of chaparral brush and oak woodlands would be intermediate (between that of grass and forest). Summarizing over all vegetation types, the predicted global warming will leave the two more southerly areas with more fast fires and fewer slow fires (Fig. 2).

Predicted changes in fuel moisture and wind speeds also caused greater burn intensity and triggered more intensive suppression efforts, also referred to as "dispatch levels" (Fig. 3). The use of extra fire suppression resources at a high dispatch level, such as air tankers and bulldozers, can lead to large increases in suppression costs. Even with higher dispatch of the available fire-fighting equipment and personnel, the number of acres burned and the number of escape fires increased in most cases. In densely populated areas, climatic change caused less impact than it did in the more sparsely populated areas—testimony to the effectiveness of heightened suppression intensity where more lives and property are at risk (Table 2). Rural areas, or regions with fewer resources for fire suppression, are thus at greater risk of having very large fires due to climatic change. In Humboldt, however, predictions of slower winds and more humidity with climate change offset the effects of increased temperatures; there was virtually no change in predicted fire danger in the forests and a decrease in spread rates in the grassland.

Climatic change increased the extent of fire damage and the number of potentially catastrophic fires in two out of three regions. The faster, hotter fires caused by climatic change outran

TABLE 2. Average annual fire outcomes by region and vegetation under present and future (double CO_2) climate scenarios.

	Number Escaped Fires			Acres Burned by Contained Fires			
	Present	Future	% Change	Present	Future	% Change	Total Fires
Santa Clara, Grass							
Grass	4.5	5.9	53%	2318	3278	41%	168.1
Brush	0.3	0.4	21%	10	13	34%	22.7
Tall Brush	0	0.0	n/a	2	4	100%	11.6
Redwood	0	0.0	n/a	2	2	7%	23.0
Total/Overall	**4.8**	**7.3**	**51%**	**2332**	**3298**	**41%**	**225**
Amador-El Dorado							
Grass	1.2	2.8	143%	1709	2189	28%	58.5
Brush	5.0	11.1	121%	221	462	109%	62.9
Oak Savanna			n/a	292	481	65%	152.8
Mixed Conifer	0.0	0.0	n/a	26	37	43%	29.0
Total/Overall	**6.2**	**13.9**	**125%**	**2248**	**3169**	**41%**	**303**
Humboldt-Del Norte							
Grass	0.0	0.0	n/a	38	28	-27%	15.1
Redwood	0.6	0.6	0%	207	198	-4%	158.9
Total/Overall	**0.6**	**0.6**	**0%**	**245**	**226**	**-8%**	**174**

fire suppression and many more acres were burned than in the current climate scenario. In the Santa Clara region, for example, contained fires in grass and brush burned 41 percent and 34 percent more area, respectively, under climate change than they did in the present climate. The number of escaped wildfires increased by 53 percent and 21 percent in grass and brush (Fig. 4). For redwood forests, which grow in moist, foggy areas, there was a small change in fire damage accompanied by

The increasing density of real estate in forested areas—exemplified by developments in much of the Amador-El Dorado region—represents the potential for enormous wildfire losses.

enhanced fire-fighting efforts (triggered by more intense fires) and higher suppression expenses.

In the Sierra foothills, the effect of climatic change was even more severe. Here, the number of potentially catastrophic (escaped) fires predicted rose dramatically—143 percent more each year in grassland and 121 percent more in brush. With the number of escaped wildfires more than doubling, climatic change could lead to a serious increase in fire damage in this region. The area burned by smaller fires—those that were contained by initial suppression—also saw large increases in all four vegetation zones. The area of brush burned more than doubled, and there was a 65 percent increase in oak savanna burned.

Climate change had little impact in California's Humboldt redwood region, thanks to comparatively slow fires, effective fire suppression and GISS predictions of a wetter, less windy climate. Like the redwood forests of Santa Clara, those in Humboldt showed almost no change in escapes or area burned. The small area of grassland did experience a decrease in burned area and suppression efforts.

More Severe Wildfire Losses

Our study addressed the direct effects of climate change on fire behavior (such as moisture content of fuels and wind speeds). It did not consider the indirect effects of climate change on plant growth or vegetation distribution because they're more difficult to quantify. Yet, as predicted by climate modelers (and as seen from the recent El Niño), increased wintertime rainfall can also lead to a higher base of flammable fuels during fire season.

In a feedback with potentially alarming consequences, wildfires may create conditions that set the stage for subsequent wildfires. Among the six vegetation types considered, fires in earlier stages of succession (grass and brush) tended to have faster spread rates and exhibit a more pronounced response to changes in climate. Wildfire effectively resets the succession clock, with newly burned areas colonized first by grass, succeeded by shrubs and then forests. More frequent or extensive fires would result in more land area covered by grass and shrub vegetation. These ecosystems show the greatest susceptibility to fire, and also the greatest response to climatic change. Consequently, the effect of global warming on wildfire may be even more severe than our models predict due to fire-induced alteration of vegetation distribution.

Other important synergies exist. In California, patterns of development are superimposed on patterns of vegetation in ways that may amplify the economic consequences of wildfire. In the Sierras, for example, population growth and housing density are often much higher in the grass, chaparral and oak woodlands common at low elevations (and within commuting distance to jobs in the Central Valley) than at higher, forested elevations farther from urban centers. Moreover, population tends to concentrate in the warmer regions of the state, regions that this analysis suggests would be most affected by climatic change. These results indicate that homes and insured property are concentrated in the zones likely to experience the largest response to climate change.

Conclusions

Damages and insurance claims due to wildfire are on the rise. While this analysis was not designed to evaluate the contribution of current, human-caused global warming to these trends, it does provide a view of what the future may hold. There are mechanistic links between climatic change and wildfire damage, and as human activities continue to contribute to climate change by emitting greenhouse gases, we can expect an increase in wildfire danger.

Understanding and quantifying the important linkages between natural disasters and climate change call for integration of many kinds of expertise. For example, while models of climate and wildfire focus on natural processes and underlying extreme events, the actuarially based loss-estimation models are focused on the economic impacts of these events. The Reinsurance Association of America has noted the opportunity and imperative for integrated assessments of climate change impacts. Association president Frank Nutter told the insurance community in 1996 that "it is incumbent upon us to assimilate our knowledge of the natural sciences with the actuarial sciences—in our own self-interest and in the public interest."

As experience has shown, any upward trend in wildfires would likely have serious consequences for the residents of California and their property. To combat these trends in the near term, local planning officials and individual homeowners need to revisit issues of fire suppression, development patterns and vulnerability of structures (through building codes, vehicle access, brush control around buildings and so on). Communities can also invest in more fire-fighting resources. But in the longer term, such efforts will likely fall short. The broader national and international issues of climate change itself and its relation to wildfire must ultimately be addressed. ●

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